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Title: New energy spectral measurements of a distributed x-ray source with a Compton spectrometer

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New energy spectral measurements of a distributed x-ray source with a Compton spectrometer

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SPIE Optics + Photonics, San Diego, CA

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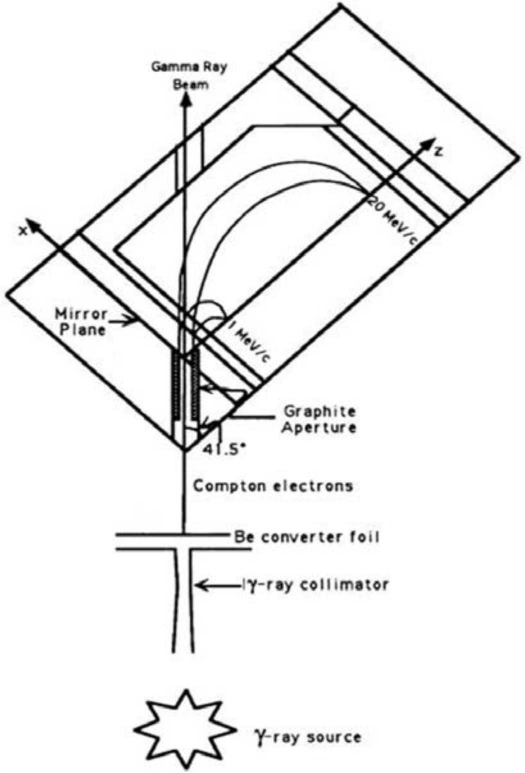
Motivation

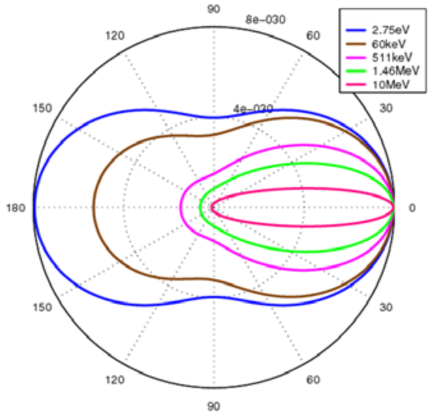
1. Accurate knowledge of photon energy spectra is required for most accurate density reconstructions from radiographic data and accurate estimation of dose.
2. Shot-to-shot variability in the energy spectrum is one limitation to understanding areal density obtained from x-ray radiography and advanced sources.
3. Multi-pulse radiographic machines alter the photon energy spectra via beam target interactions. Knowledge of the energy spectra at each pulse is necessary for the most accurate density reconstructions and confirmation of hydrodynamic behavior.

Why use a Compton spectrometer? *Directly measures energy spectra of X-ray beams produced at Radiographic Test Facilities. It is necessary to reduce the photon intensity in order to avoid pulse pile-up and radiation damage to the detector.*

Principle of operation

- Electrons are easier to direct
  - Lowers the flux
  - Energy selection by bending in a magnetic field
- Correlation between e- position and gamma energy





Klein-Nishina distribution
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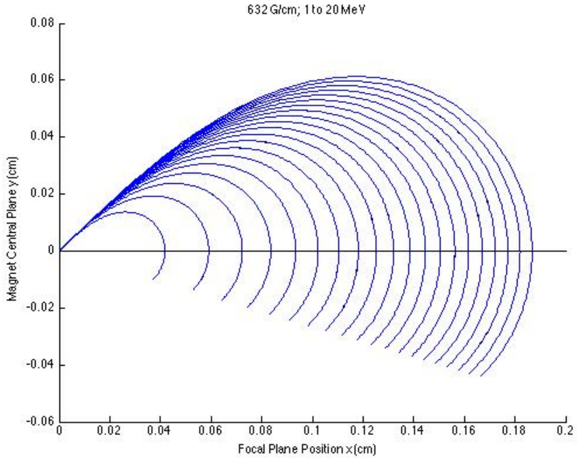
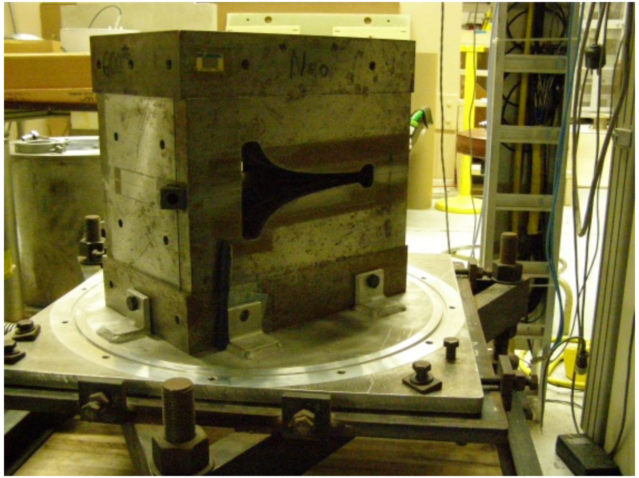


[1] *Morgan et al., Nucl. Instr. And Meth. A308 (1991) 544*

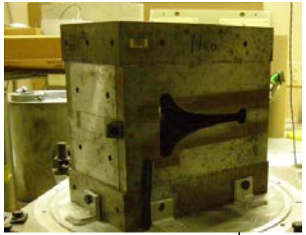
The Compton spectrometers

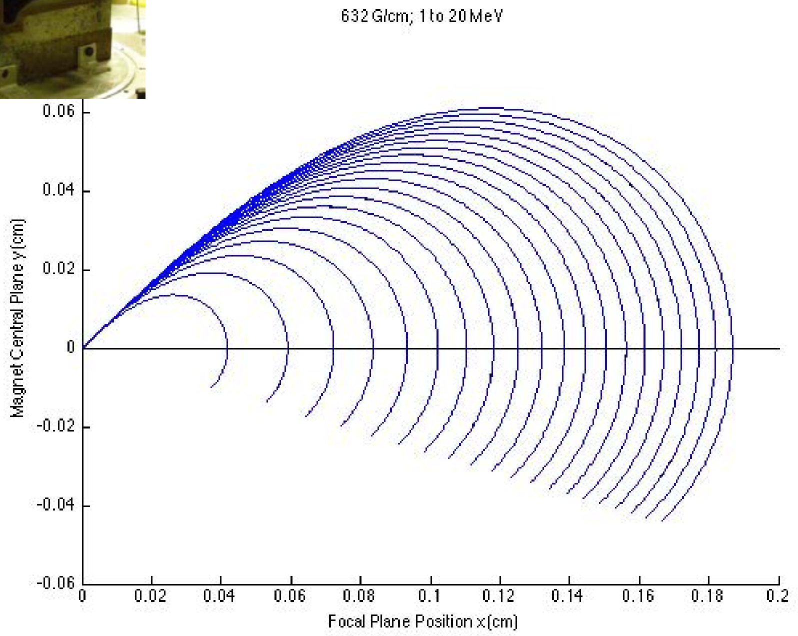


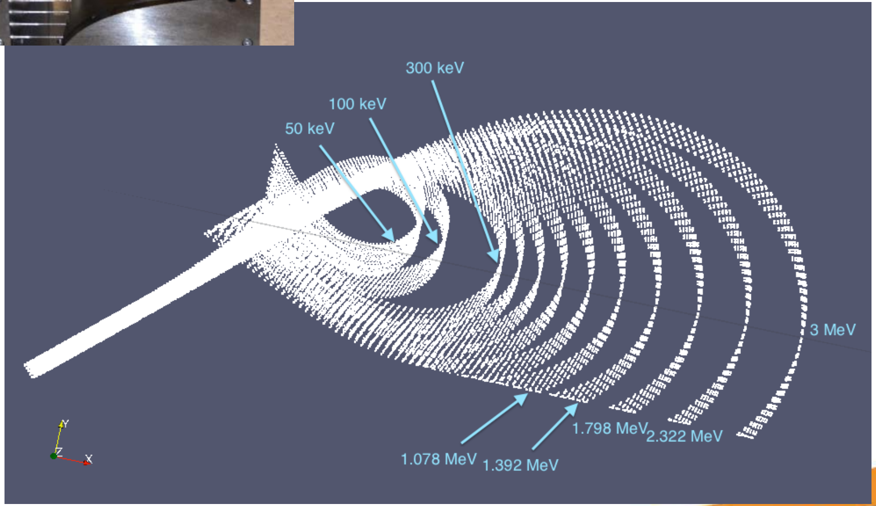
632 G/cm field gradient
0.5 to 20 MeV
300 kg
NdFeB

118 G/cm field gradient
<0.1 to 4 MeV
~250 kg
SmCo

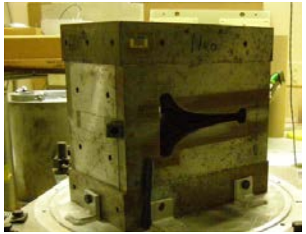
The Compton spectrometers

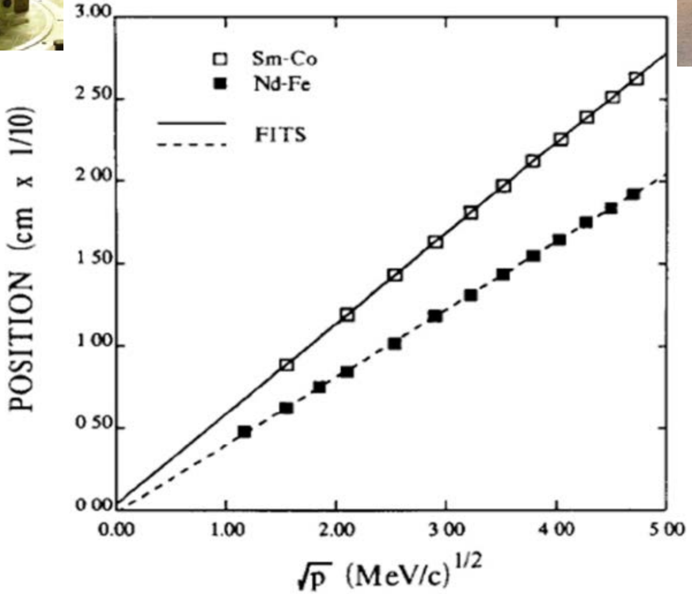


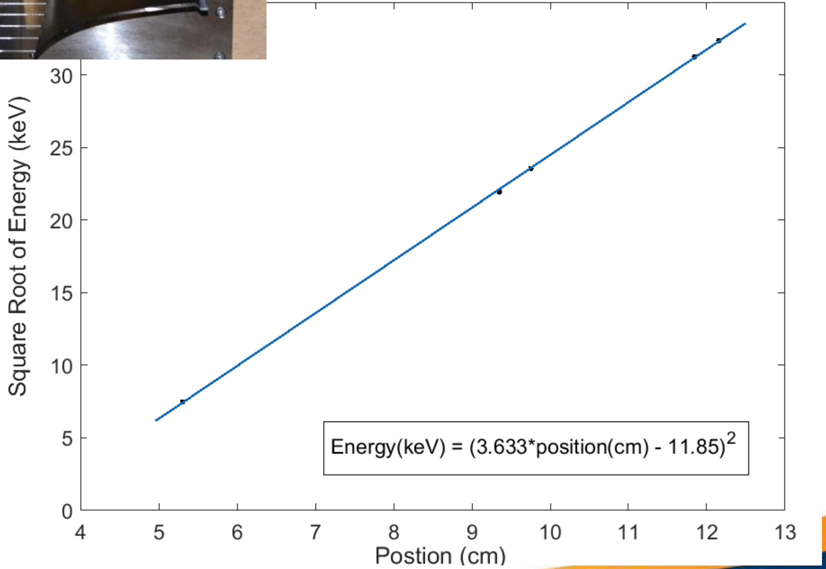




The Compton spectrometers



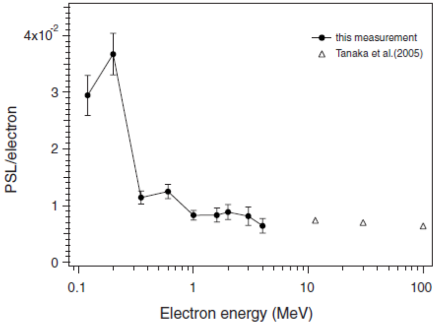


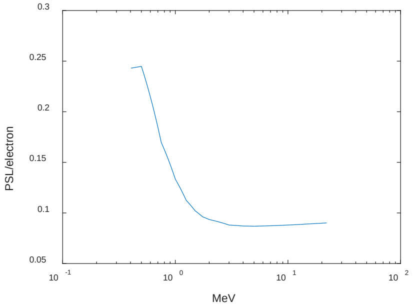


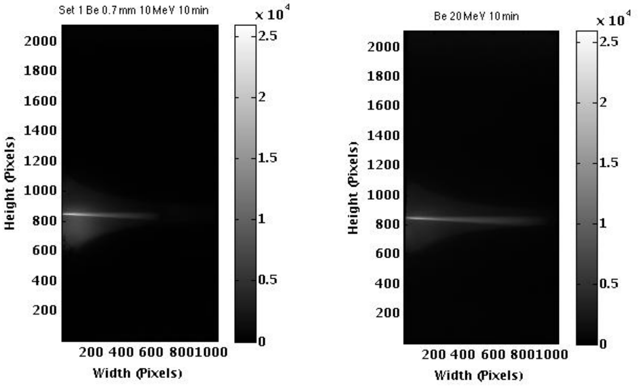
[1] *Morgan et al., Nucl. Instr. And Meth. A308 (1991) 544*

Data acquisition with image plates

- Feed in through the top
- Have to break vacuum
- Introduces ~mm position uncertainly in focal plane
- Requires calibration of IP response

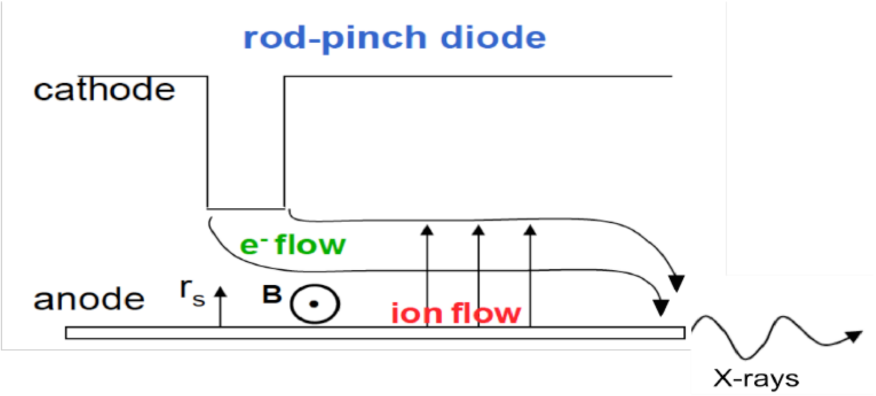






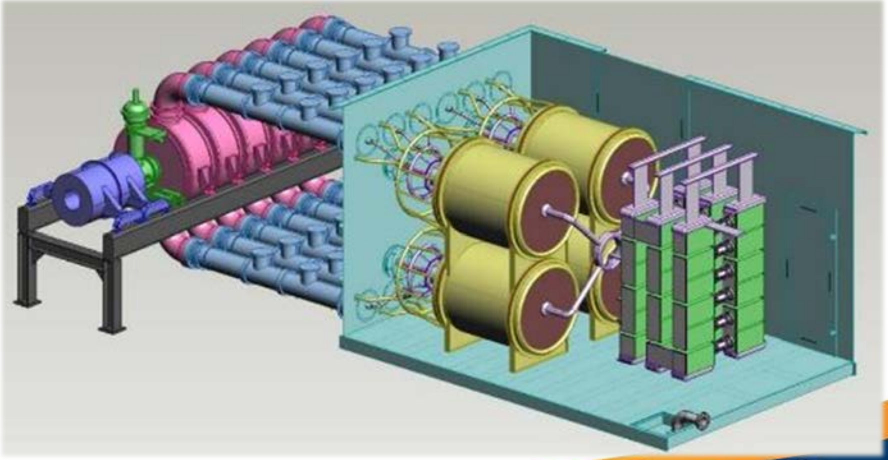
Measurement of Mercury in Large-Area Diode (distributed source) configuration

Point source example – MerCy mode



Spot size ~0.75 mm, 5 rad @ 1 m, 2.25 MeV endpoint

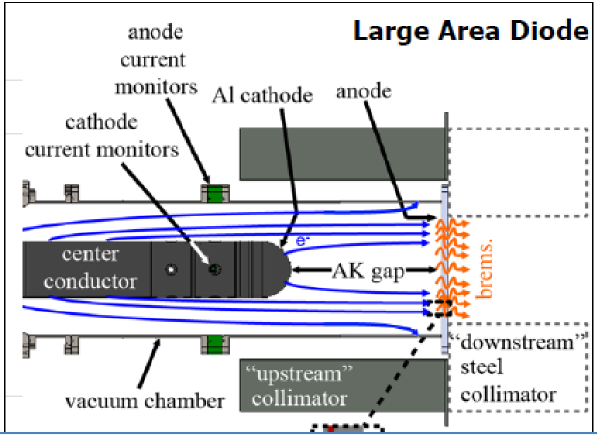
CAD model of Mercury (nominally a -8.2 MV, 200 kA pulsed-power machine)



Measurement of Mercury in Large-Area Diode (distributed source) configuration

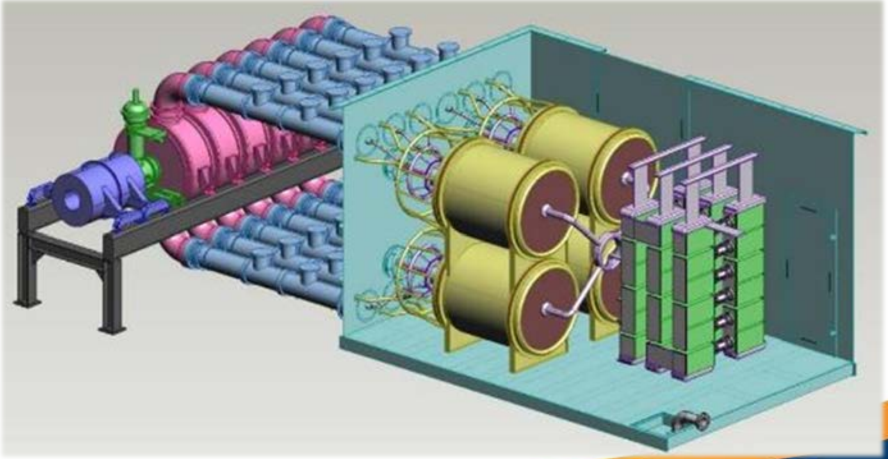
Principle motivation – validate x-ray model of Mercury in LAD configuration, 5 MeV endpoint

Distributed source example – LAD mode

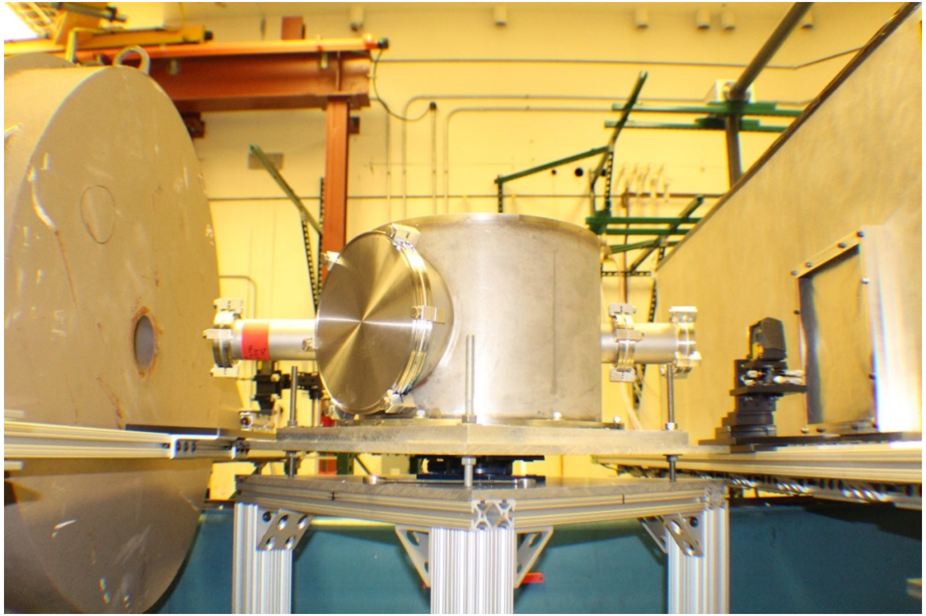


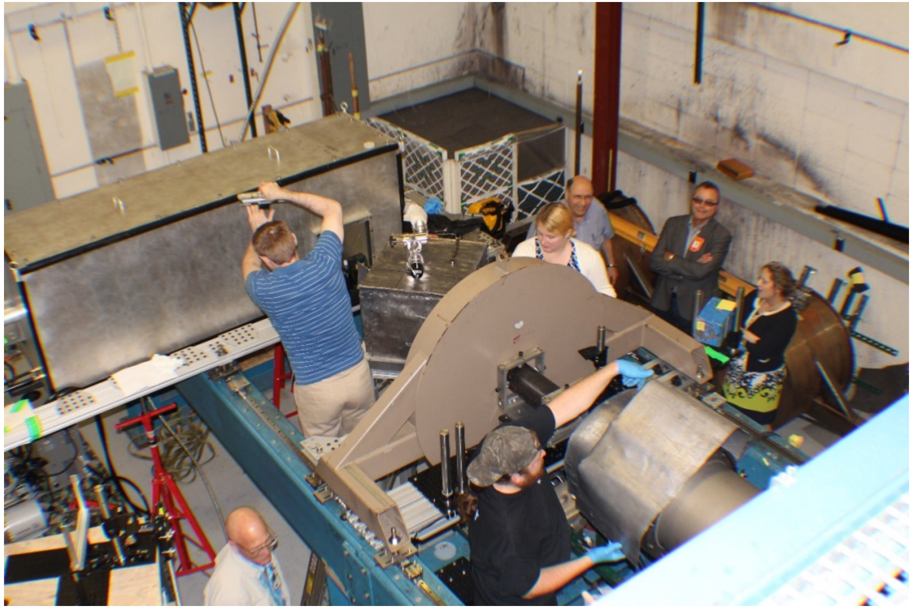
Spot size >15 cm annulus, 175 rad @ 1 m, 5 MeV endpoint

CAD model of Mercury (nominally a -8.2 MV, 200 kA pulsed-power machine)

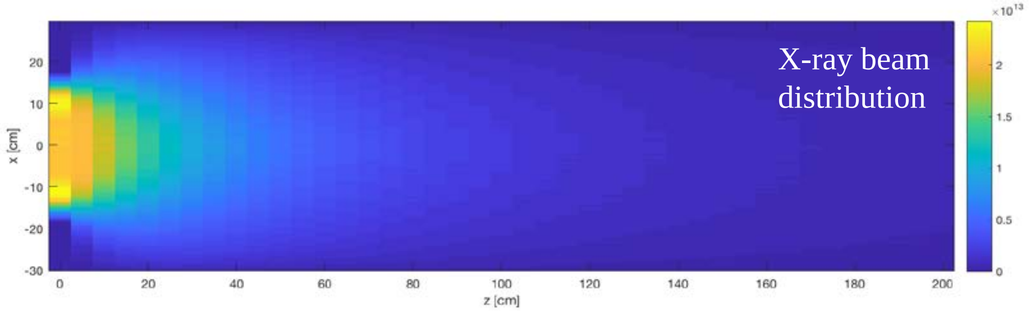


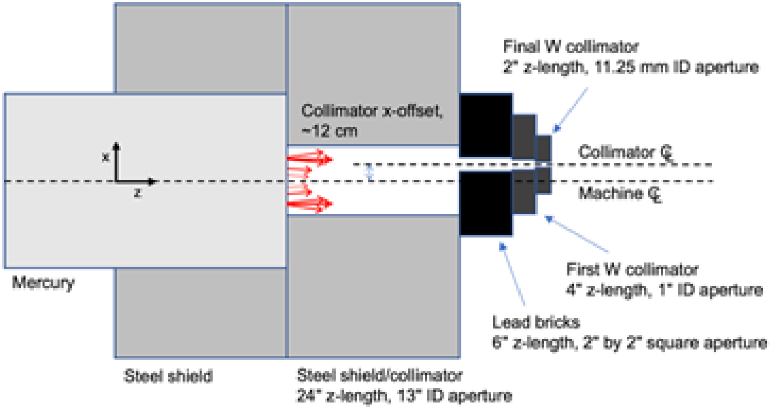
Naval Research Laboratory – Mercury Facility

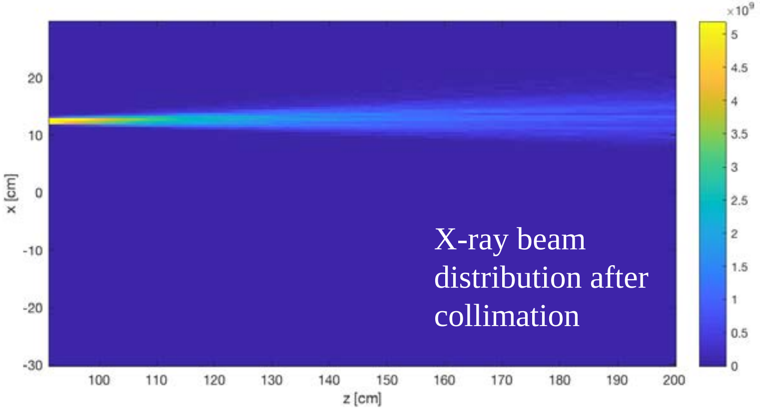




Simulations, collimation, and shielding

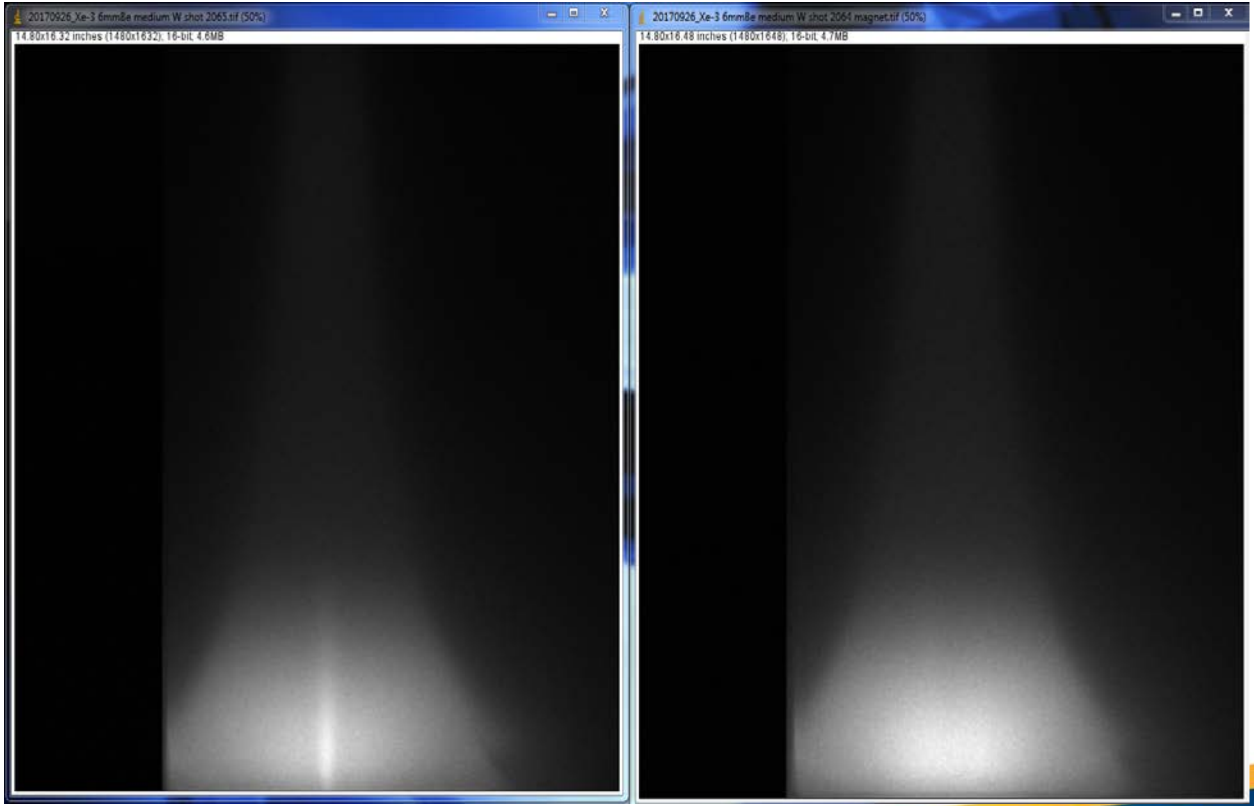




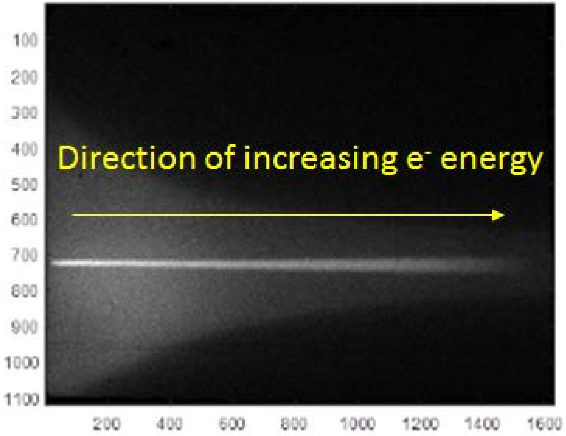


12 cm off-axis; 1.1 m from source, 6 mm Be convertor foil

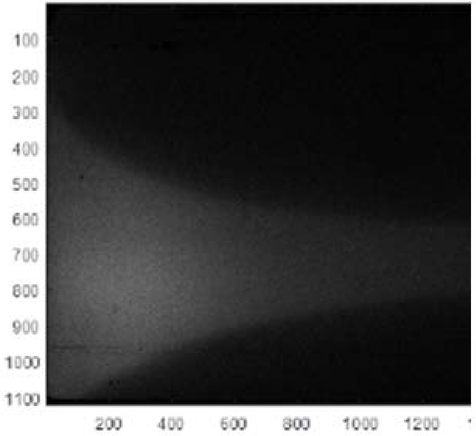
Sample Image Plate Scans



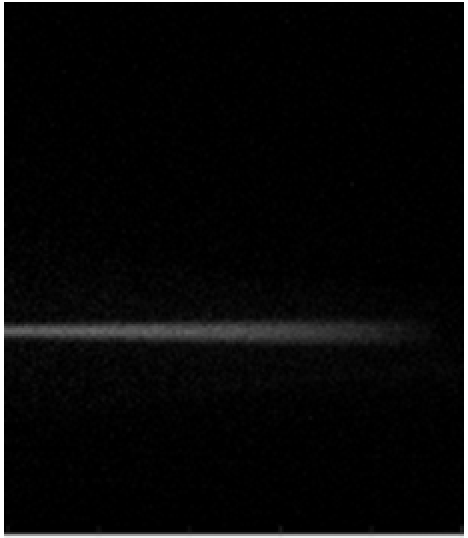
Background subtraction



Total Signal

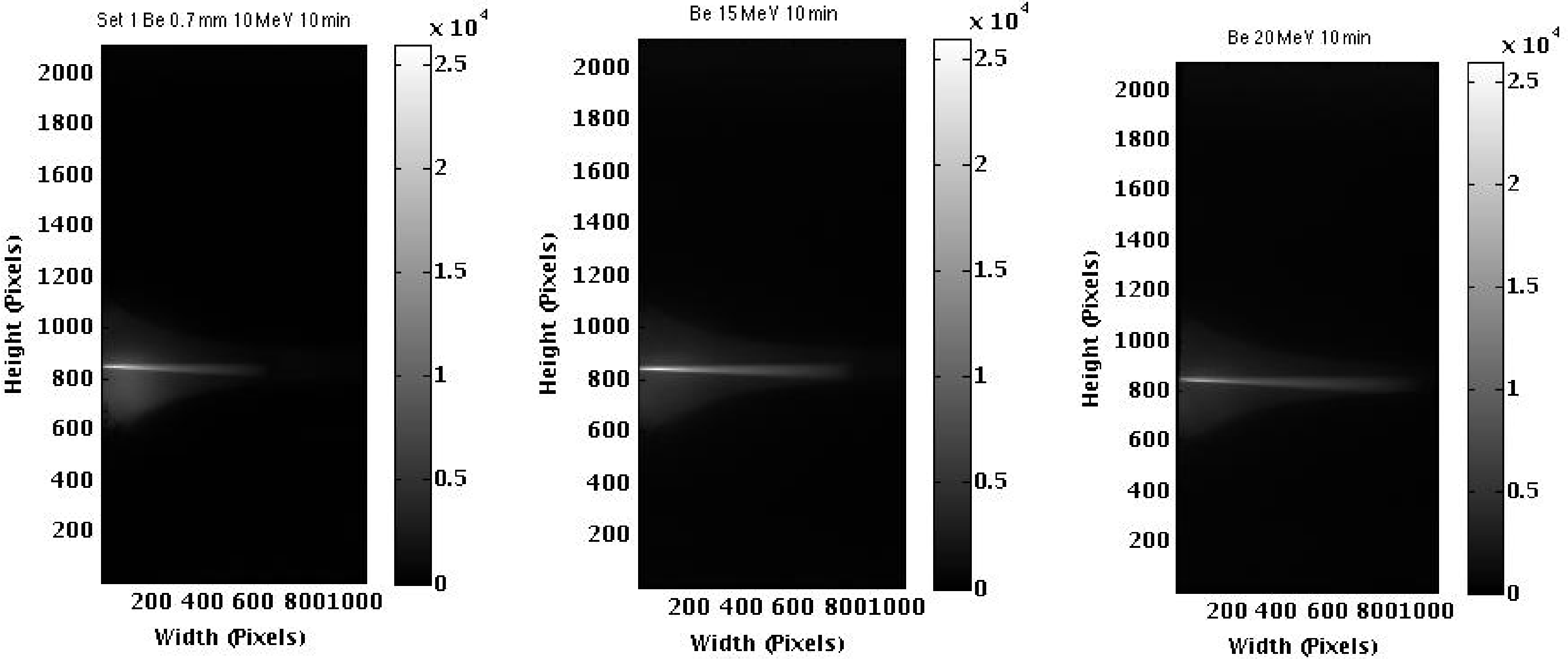


Background



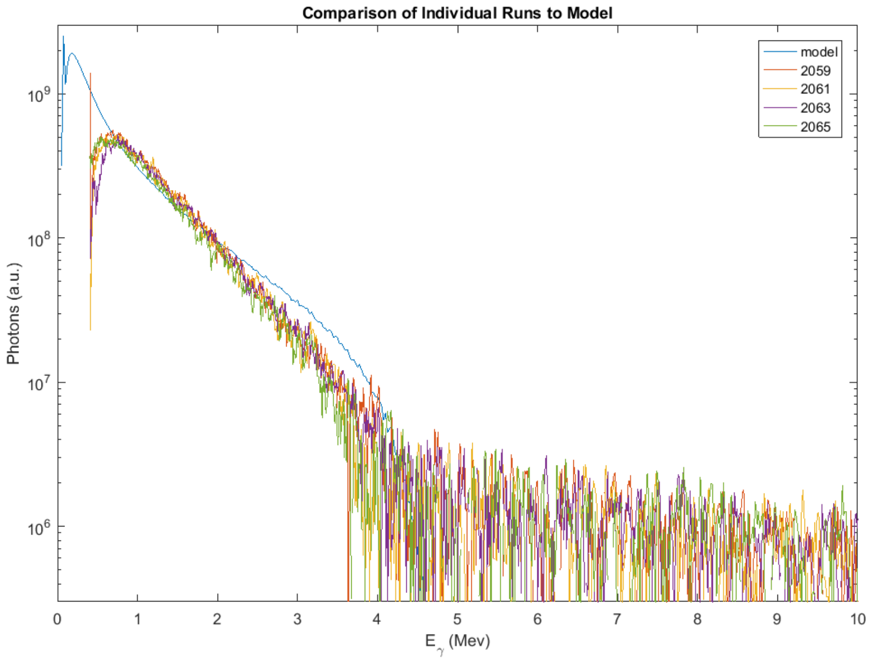
Background subtracted Signal

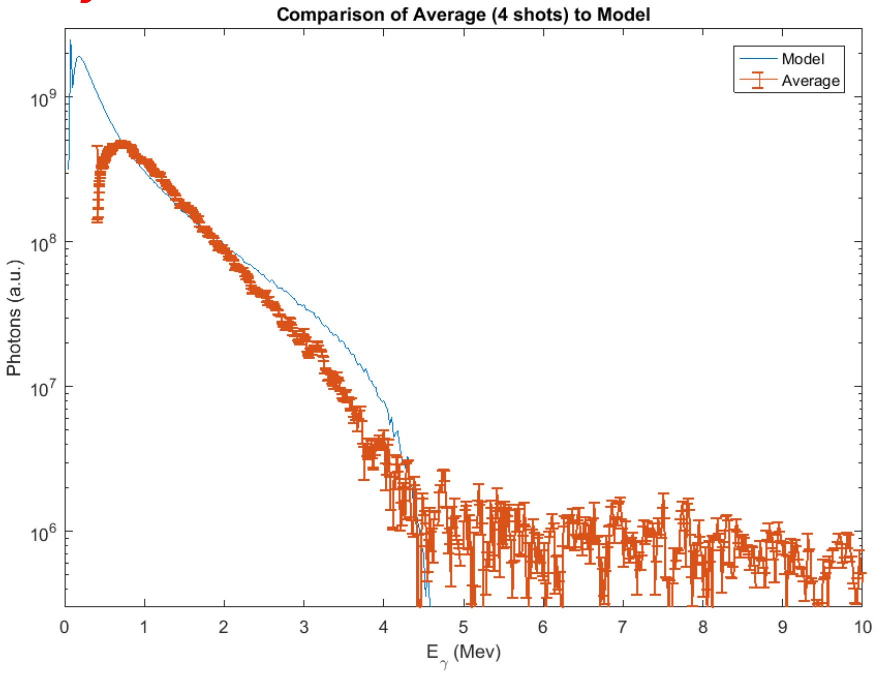
Storage phosphor images



Single-shot and average spectra

Preliminary





Spectra normalized at 1.6 MeV

Conclusions

- Compton spectrometers could allow for a single-pulse, complete spectrum measurement, complementing the standard simultaneous step wedge measurement
- ***The first spectral measurement of a distributed source was successfully completed at NRL's Mercury machine (bremsstrahlung LAD, 5 MeV endpoint)***
- No flash radiographic source with should be operated without an active spectrum measurement if possible

Future Experiments:

- High energy spectrometer – second axis of DARHT, 4 pulses; FXR, 2 pulses; HERMES III (distributed source)
- Low energy spectrometer - More Mercury and Cygnus measurements (large-area diodes)

Acknowledgements

P-23: Todd Haines, Monty Wood, Petr Volegov, Frank Merrill, Nick King, George Morgan
AET-6: James F. Hunter, Kelly Vansyoc, Cort Gautier, Johnny Martinez
P-21: Larry Schultz, Al Urbaitis, Shaun Newman, Chris Tomkins, Mark Peters, Marc Klasky, Rachel Morneau
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NEN-1: Anthony Belian C-NR: Michael James
SNL: Tim Webb and the RITS techs
NSTec: Tim Meehan, Manuel J. Manard, Rusty Trainham
NRL: Jacob Zier, Steve Richardson, Tony Culver, Brian Sobocinski, Joey Engelbrecht

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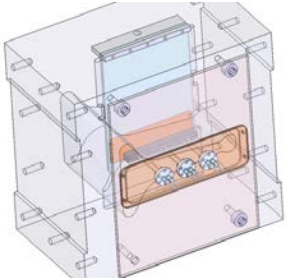
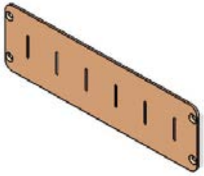
Microtron operation: John Stearns, Steve Fresquez, Kelley Vansyoc
Magnetic field map: David Barlow & Austin Patton
The folks at the Idaho Accelerator Center
Summer students: S. Bigley, M. Wortham, M. Woulfe, E. Peets, O. Englert-Erickson, S. Nielsen

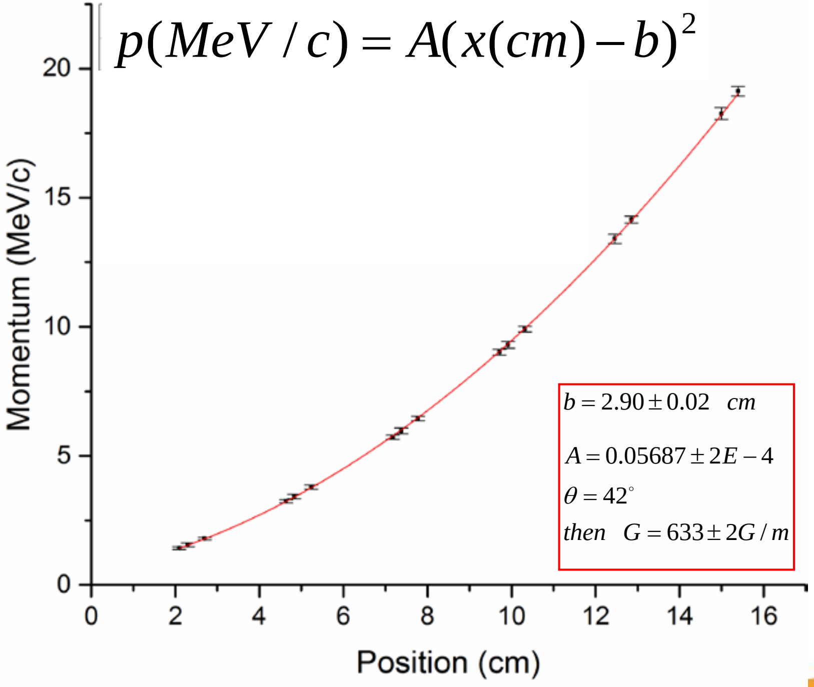
Thank you for your attention!
Questions?

Calibration: Energy vs. position

- July 2014 at the Special Technology Lab, National Security Technologies
- Continuous ion beam
- H^- and OH^- accelerated to known energies (from 1-45 kV)
- 6 brass “button” detectors along focal plane, connected to ammeters
- 2 masks in front of detectors; restrict focal plane to 16 known positions



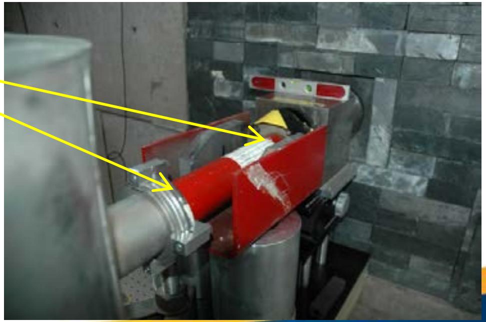




Measurements at the Microtron

- Bremsstrahlung x-ray source electron endpoint energies 6, 10, 15, 20 MeV
- 5 mm tungsten collimator, reduced further to ~2 mm
- Sweeper magnet
- 2 - 4° angular acceptance

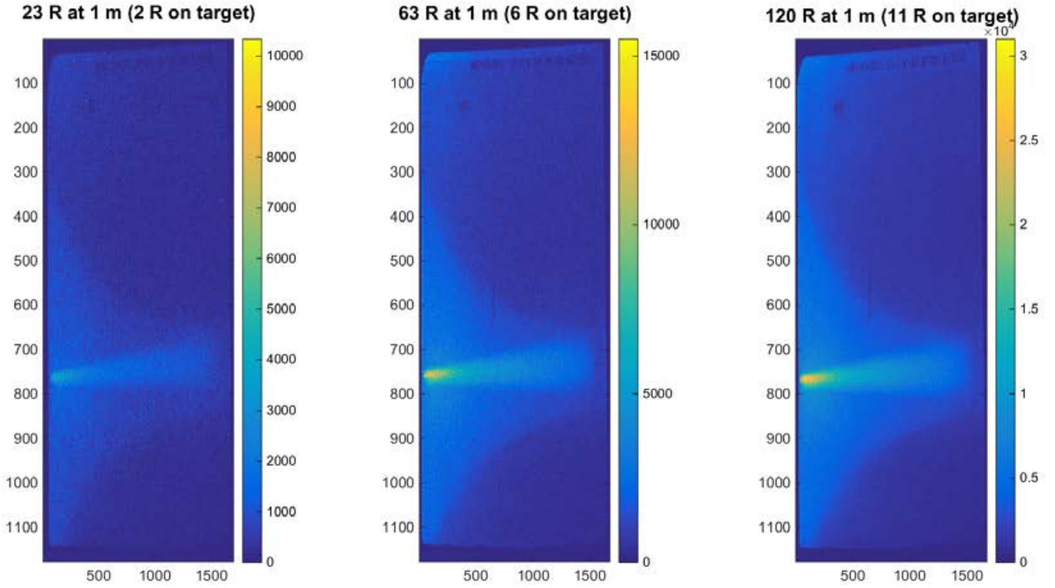
Two target positions
Upstream
Downstream



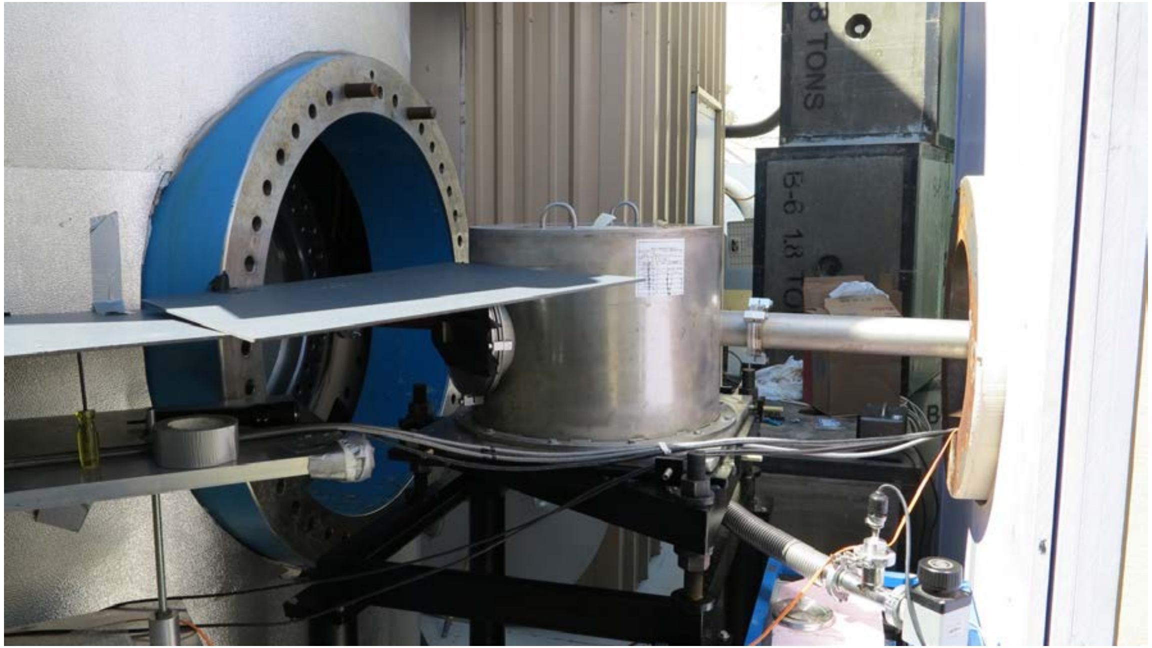
Flux – how low is feasible?

For most facilities, about 10 R @ 1m

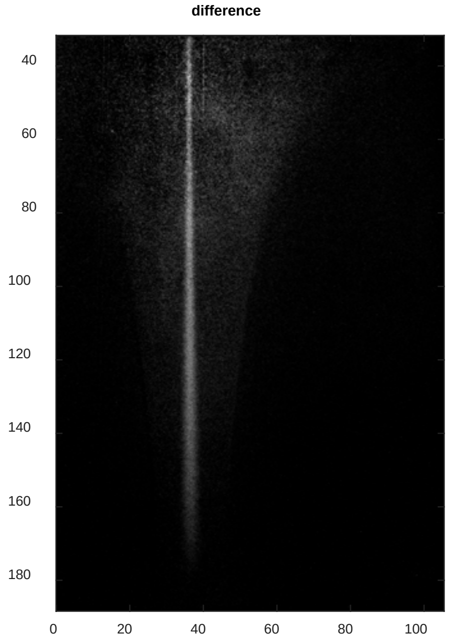
Not at issue for Microtron, DARHT, or RITS – but could limit Mercury and Cygnus

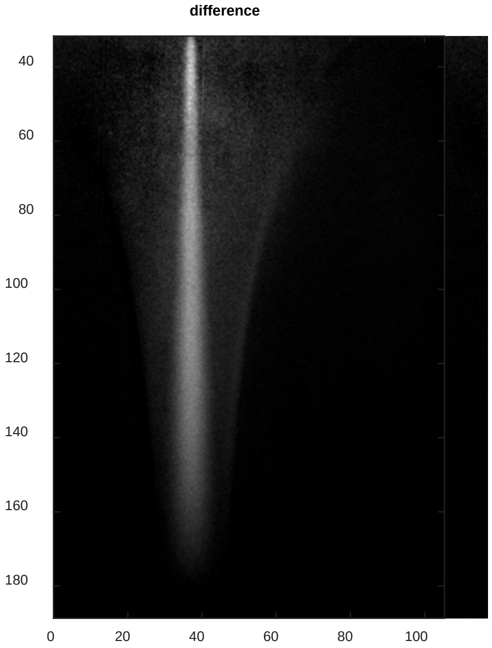


Measurements at DARHT



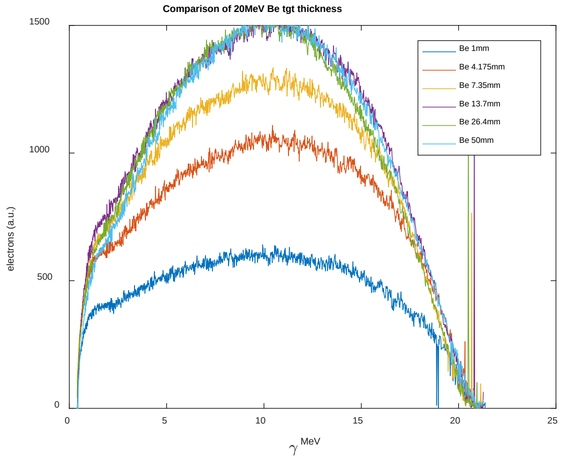
Angular acceptance: Upstream vs. Downstream

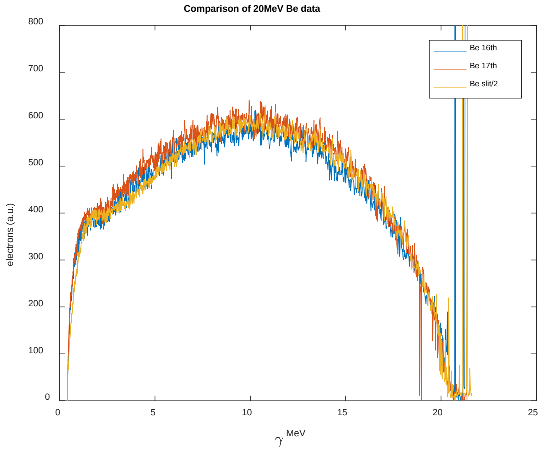




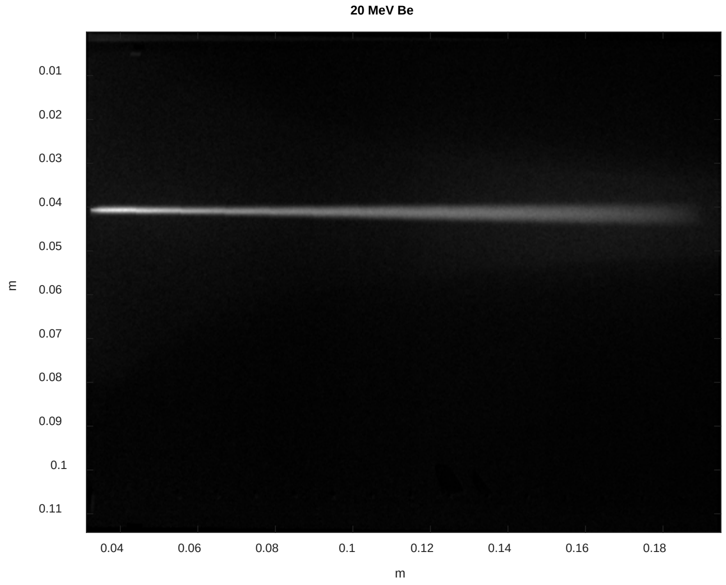
Getting even more flux……

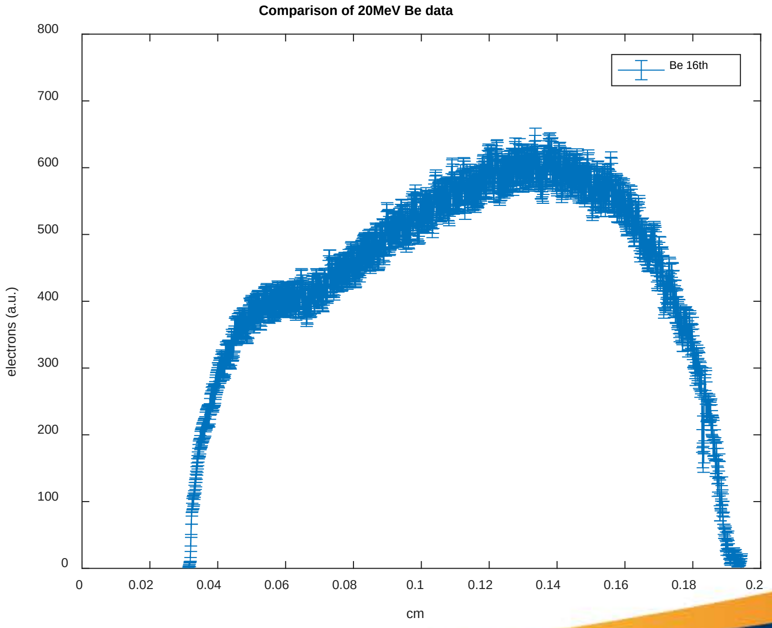
- We can get 2X more signal with a thick Be target
- We can get 2X more signal with a slit collimator
- These should add up





What we really measure are electrons on the focal plane



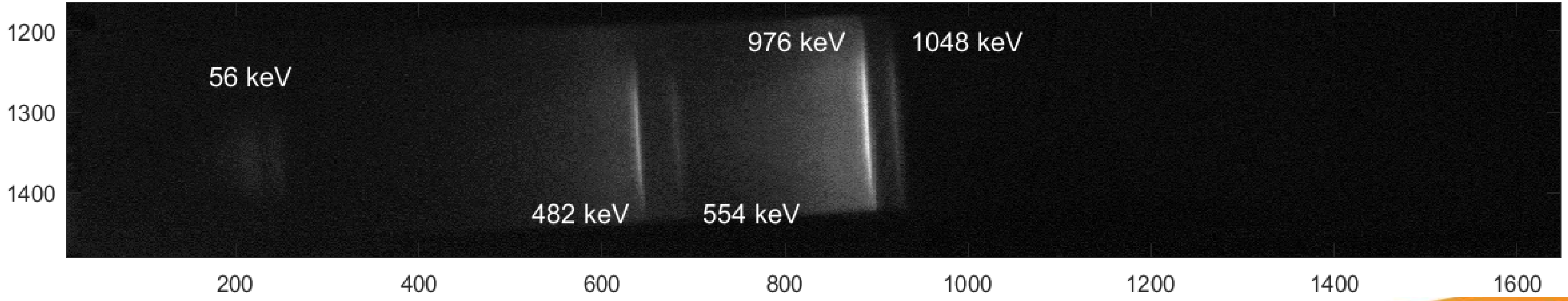


Spectral measurements with the small spectrometer

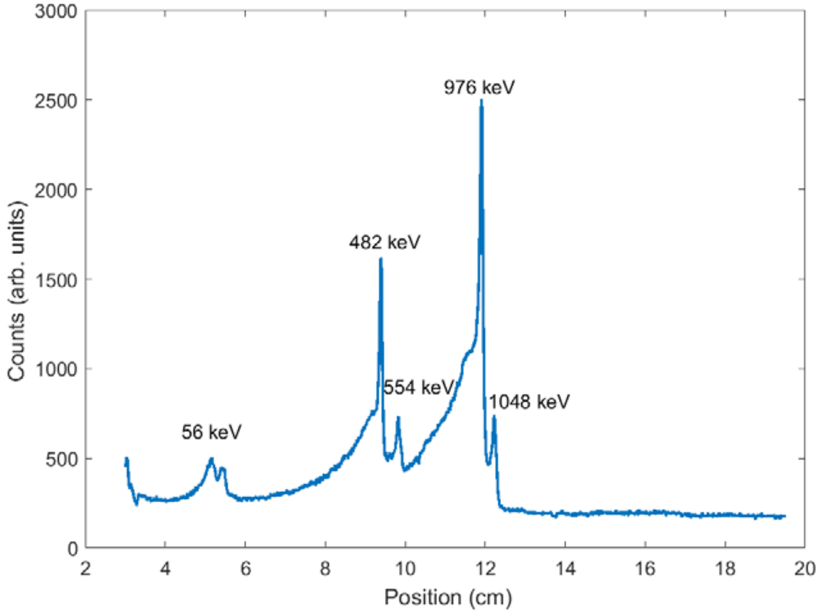
- Initial calibration with weak 207-bismuth sealed source
- Linatron – continuous bremsstrahlung spectrum with advertised 3.5 MeV endpoint, 2.5 Gy/min @ 1 m
- Mercury (in MerCy mode) at the Naval Research Laboratory – 50 ns pulse, 4 rad @ 1 m
- Cygnus radiographic machines at the Nevada National Security Site – 50 ns pulse, 4.5 rad @ 1 m

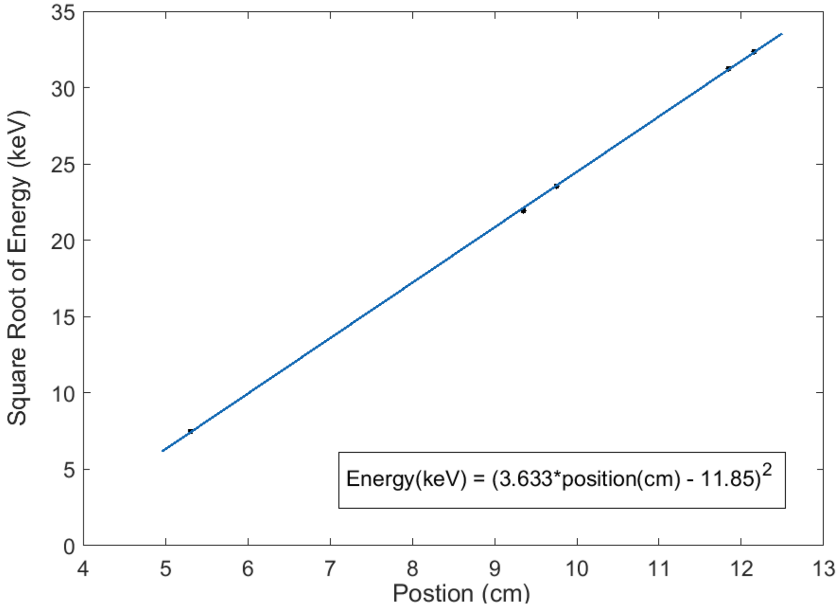
207 Bismuth calibration

- Source placed in magnet entrance for 24 hours (10 uCi)
- Internal conversion electron lines provided known energy positions



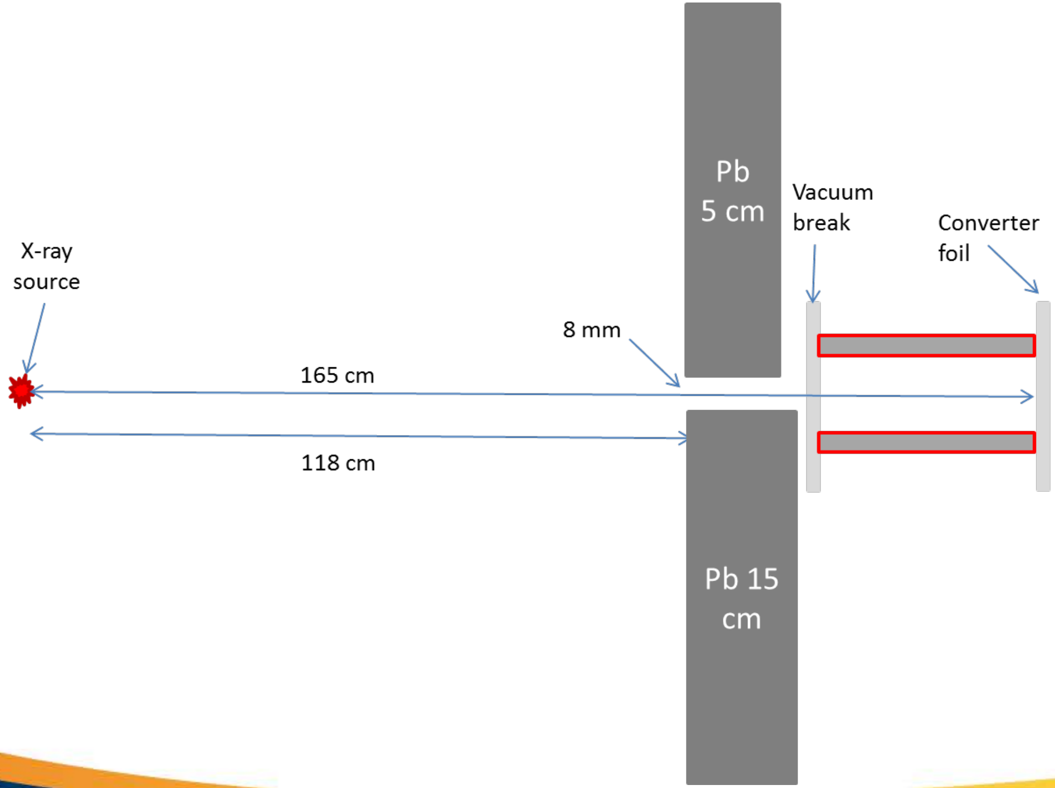
Preliminary calibration



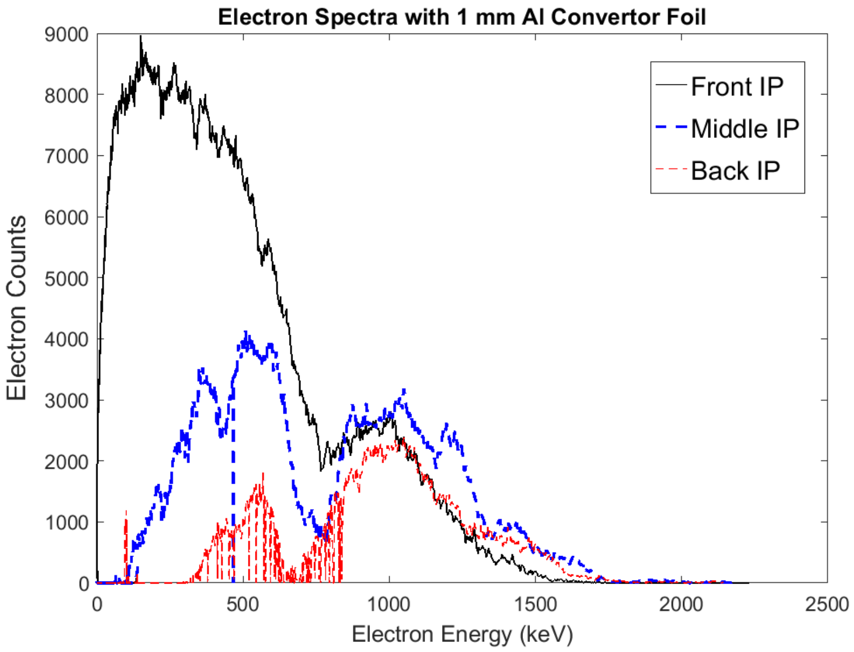


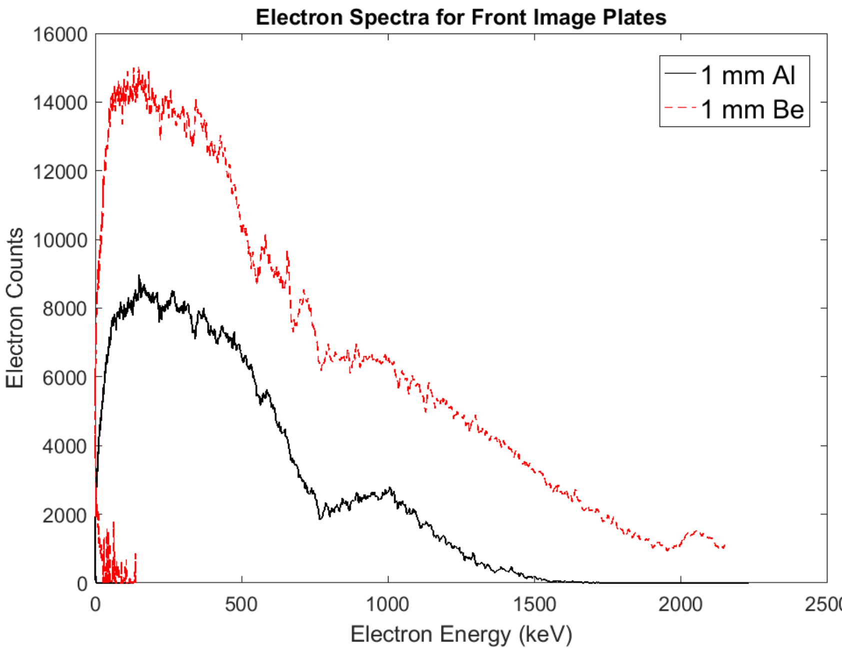
Future calibration at an electron linac will extend the range of energies

Linatron spectral measurement



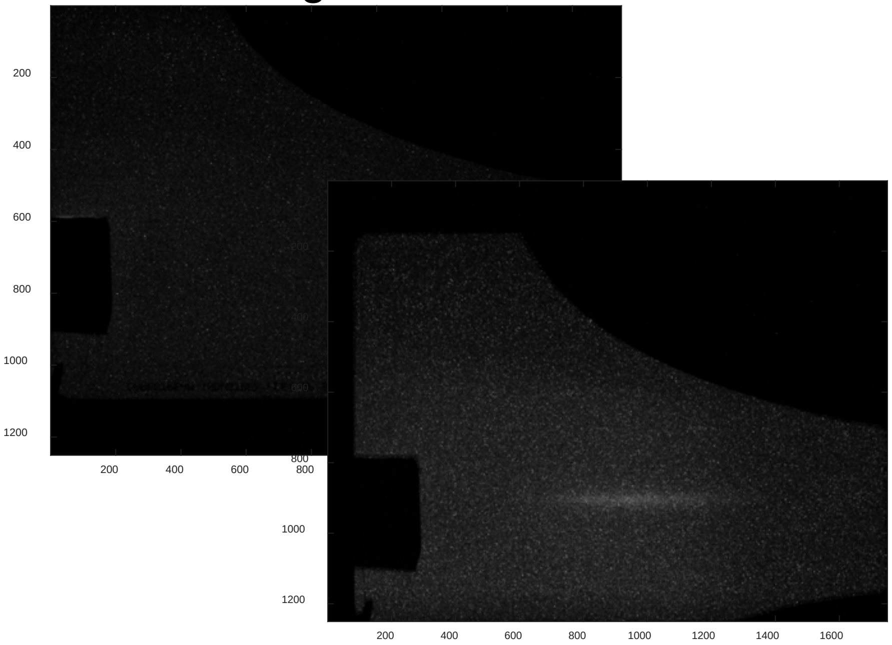
Linatron spectral measurement



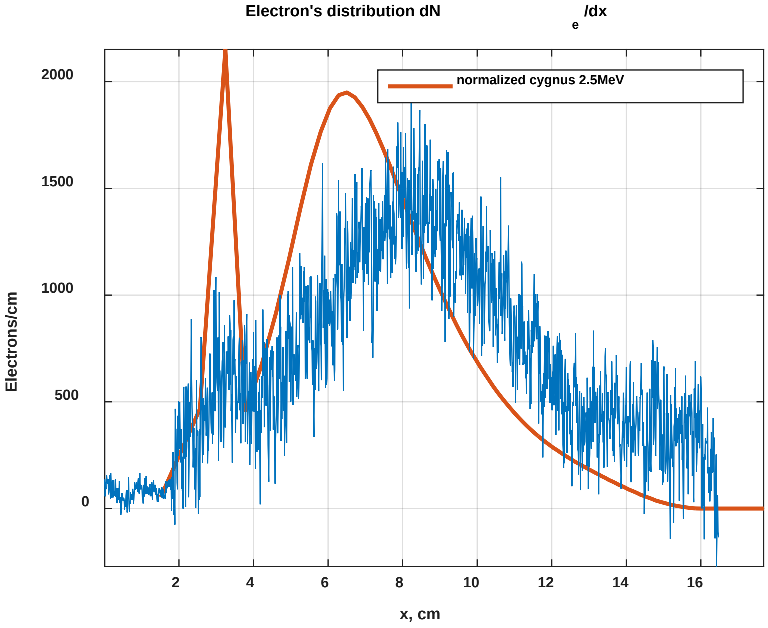


Images and preliminary Data

Background

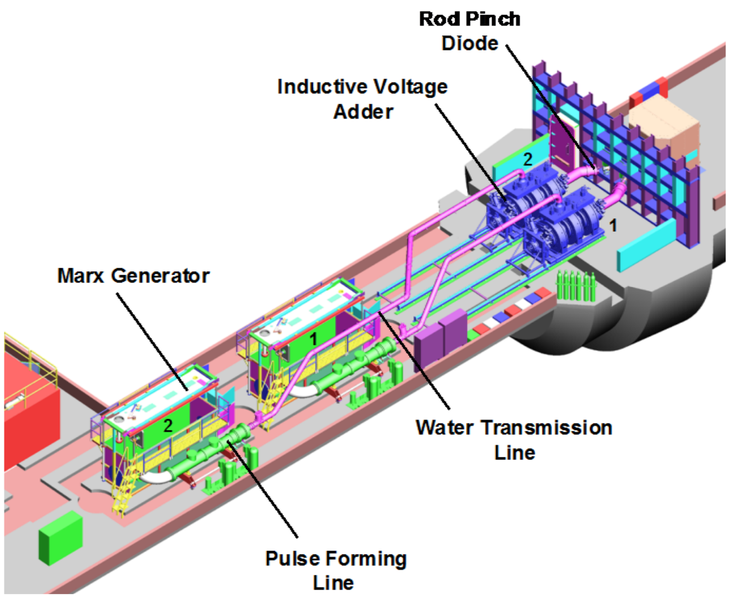


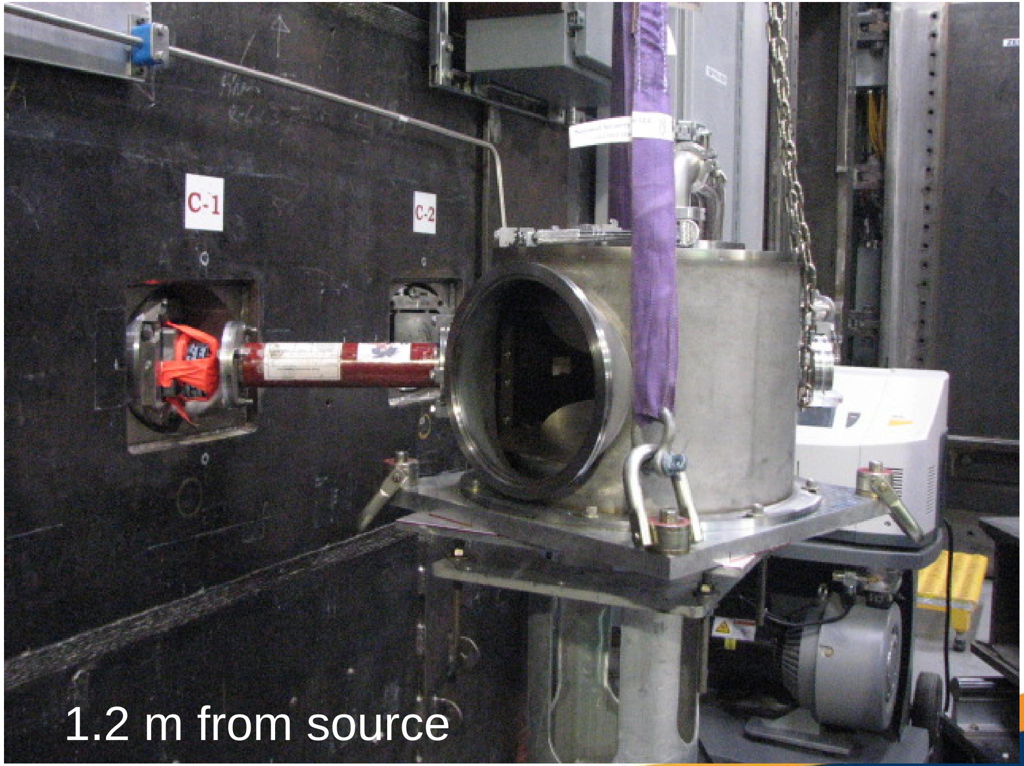
Average of two shots



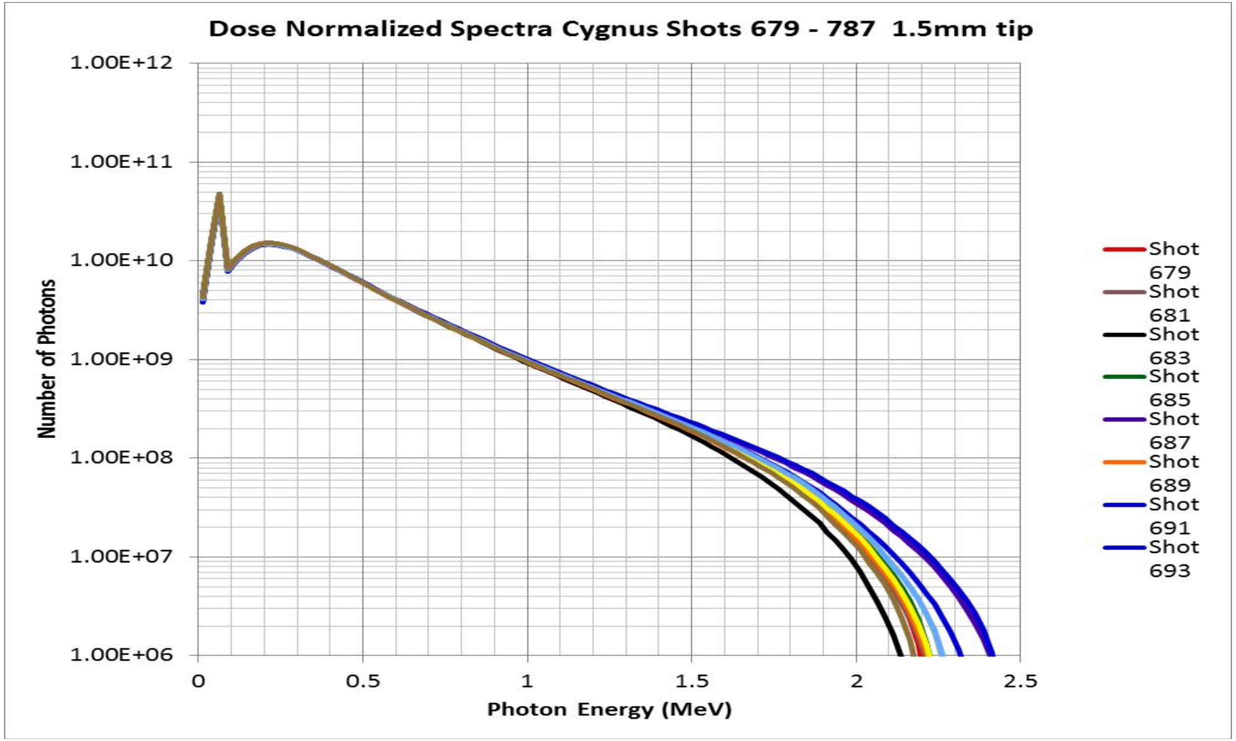
Mercury configured in “Cygnus mode”
Uncorrected data (windows, etc)

Experimental setup at Cygnus





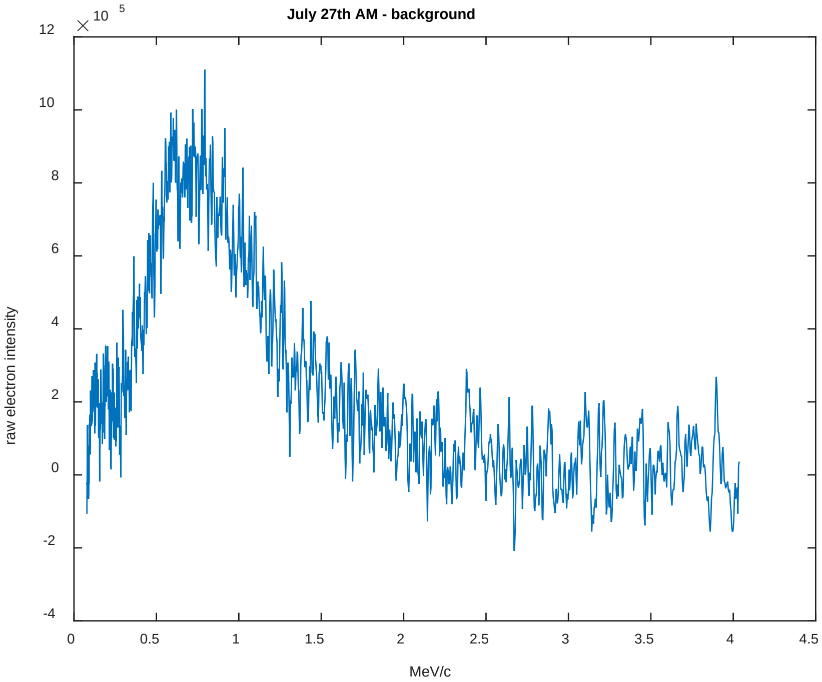
Spectral variation from step wedge data



Courtesy of Monty Wood

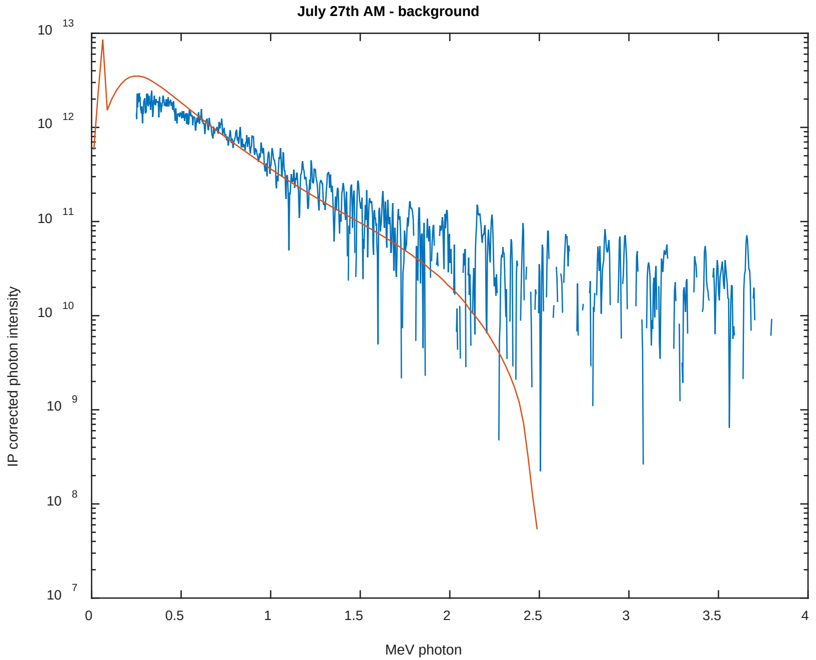
Inferred from I, V measurements & modeling

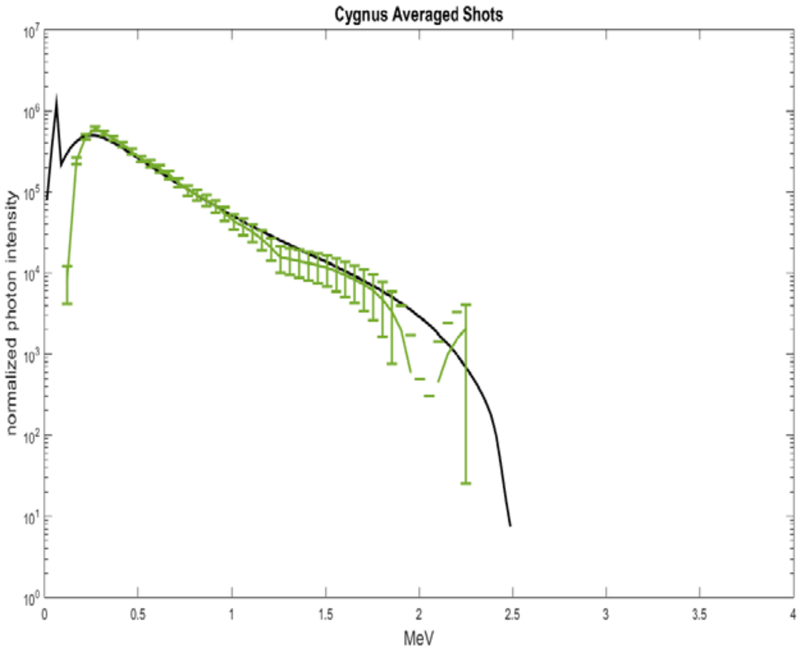
Sample electron spectrum from Cygnus



Dose normalized, background subtracted, average of 2 shots

Preliminary photon spectrum with comparison to model





Left: Dose normalized, background subtracted, average of 2 shots
Right: Average of 8 shots

And then the magic hap

The relationship between the electron detection on the image plae and the photon energy spectra can be expressed as

$$R \cdot \vec{s} = \vec{m}$$

Where R is the response matrix, $\vec{s}$ is the unknown photon spectrum , and $\vec{m}$ is the electron distribution on the focal plane.

R is determined from MCNP6 simulation of mono-energetic photons impinging on the Compton converter and mapped onto the focal plane with a quadrupole magnetic field